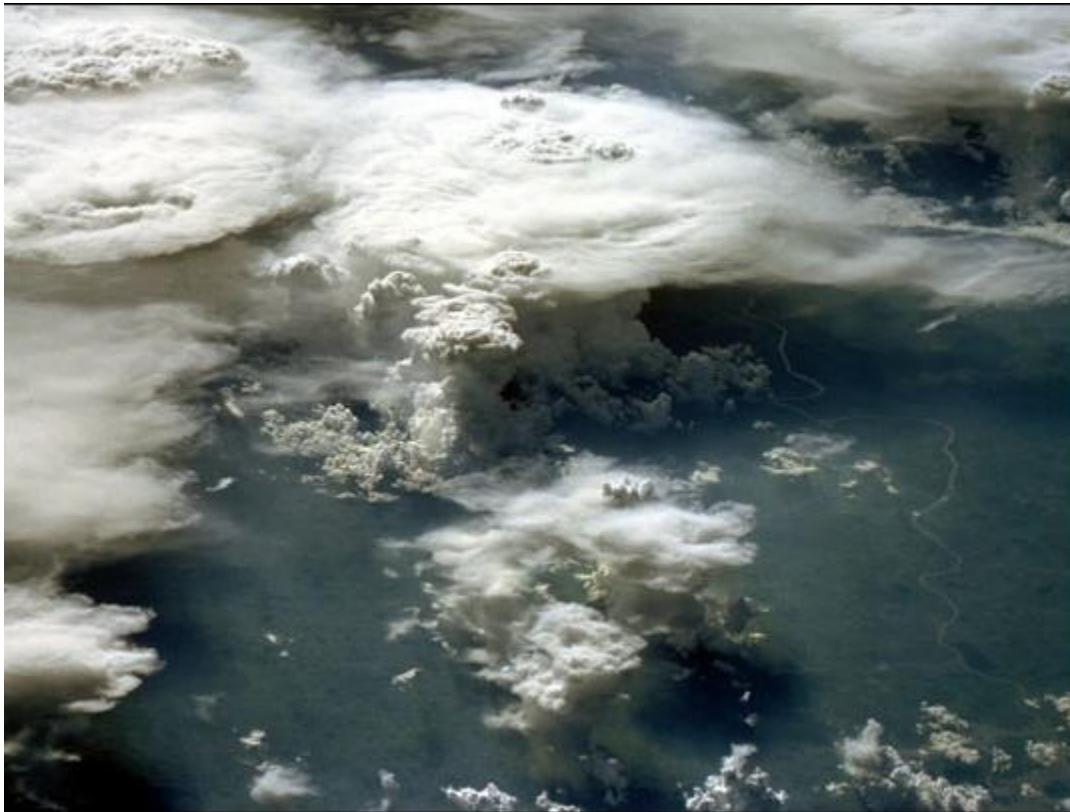


THE DIURNAL CYCLE OF CONTINENTAL CONVECTION



Tony Del Genio and Jingbo Wu

GISS lunchtime seminar, 12/2/09

A black and white photograph of two men in a research setting. On the left, a man wearing glasses and a light-colored shirt is leaning forward, resting his head on his hand in a gesture of deep thought or stress. On the right, another man wearing glasses and a patterned shirt is looking towards the screen. They are positioned in front of a large computer monitor which is not visible in the frame.

**Cloud-Resolving
Model**

**GCM
Parameterization
Developer**

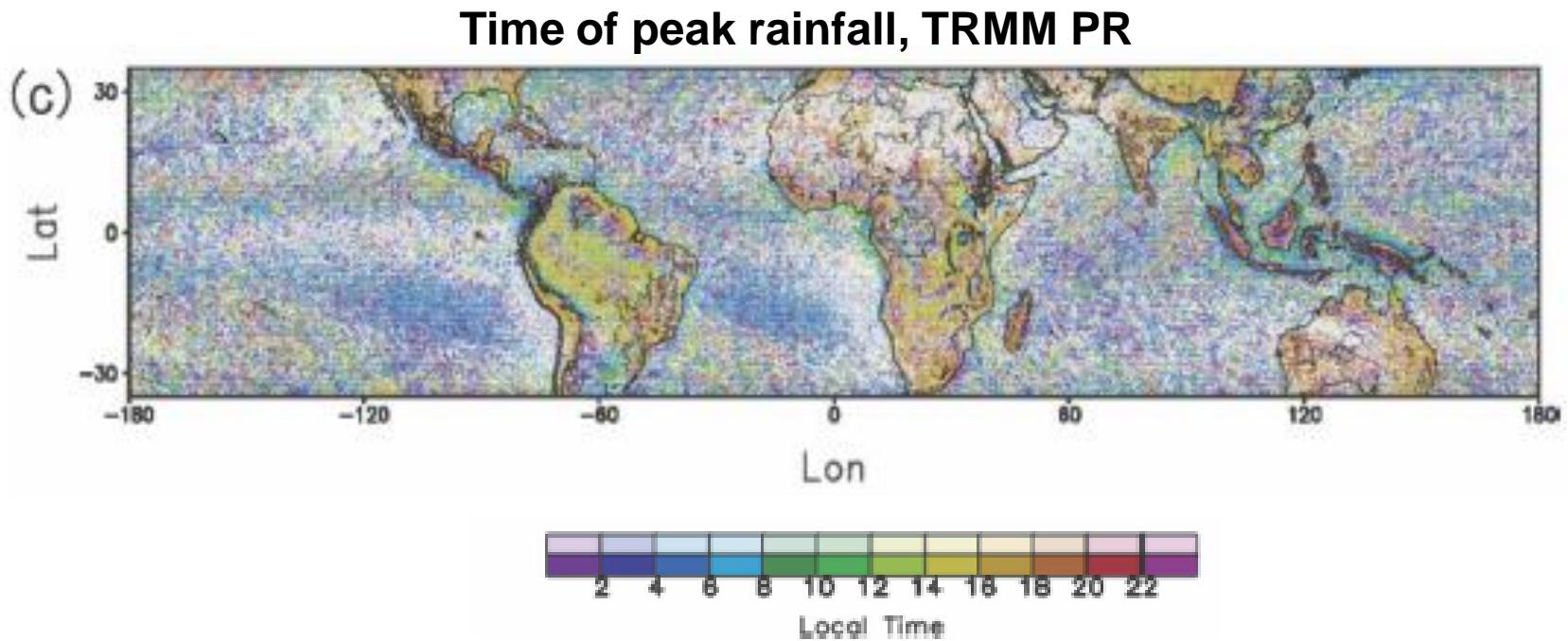


↔

~ 1 GCM gridbox

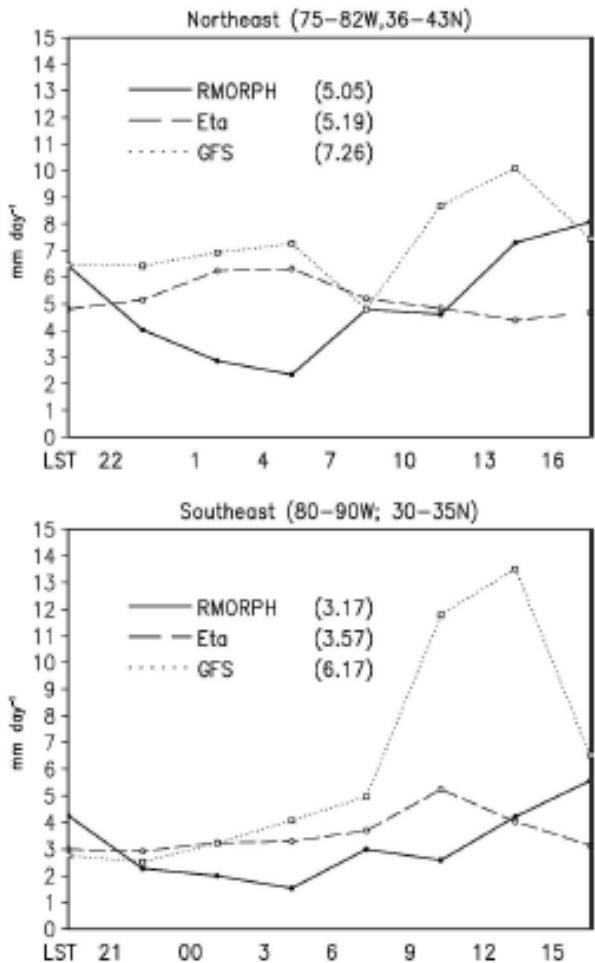
(courtesy M. Khairoutdinov)

Continental rainfall rates tend to peak in mid-late afternoon or evening

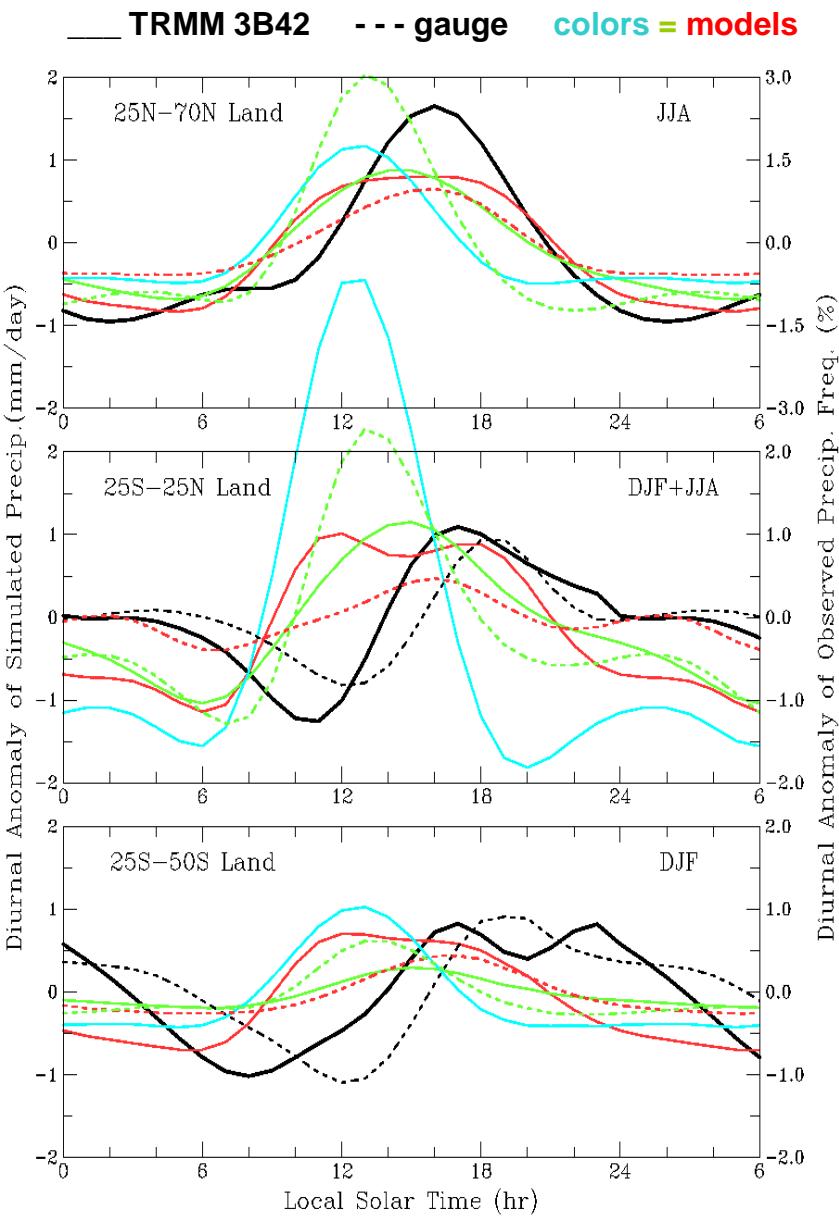


Hirose et al. (2008)

But not in GCMs, which like to rain near noon



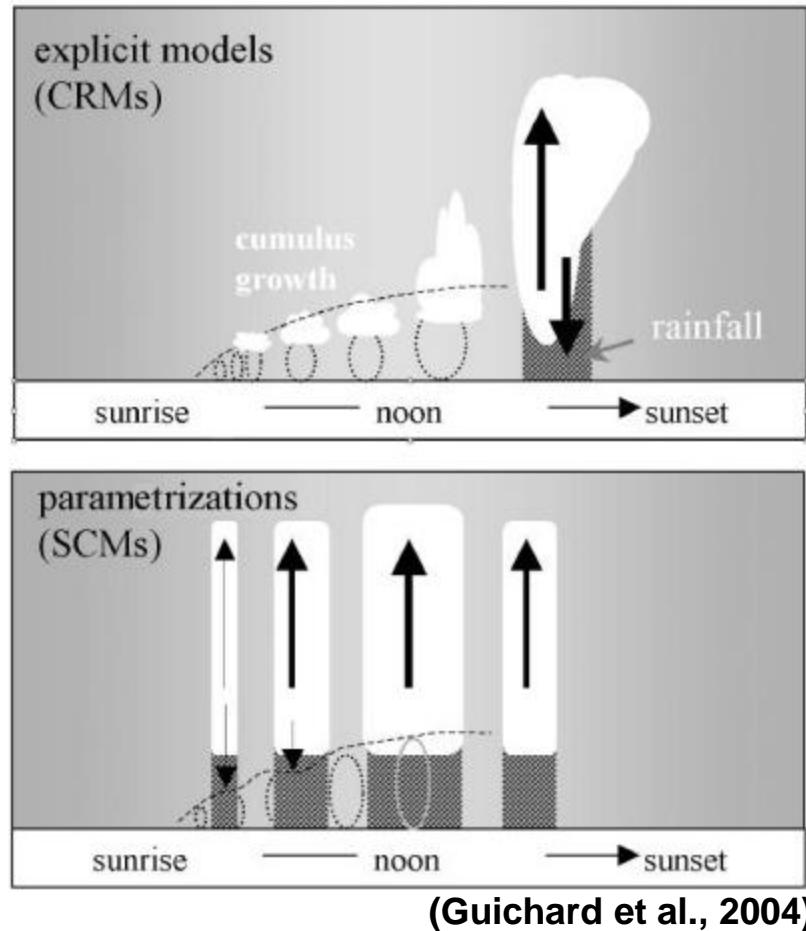
Eta, GFS 36-60 hr US forecast
(Janowiak et al., 2007)



IPCC AR4 models (Dai, 2006)

Many factors influence the timing of continental precipitation (Nesbitt and Zipser, 2003; Yang and Smith, 2006; Sato et al., 2009; etc.):

- **External factors (land-sea breeze, monsoon, topography, low level jet, etc.) – in principle can be resolved by GCMs**
- **Physics of convective cloud systems (triggering, entrainment, downdrafts, mesoscale organization, propagation) – parameterized in most GCMs**



(Guichard et al., 2004)

Let's focus on entrainment and downdrafts – what can CRMs tell us?

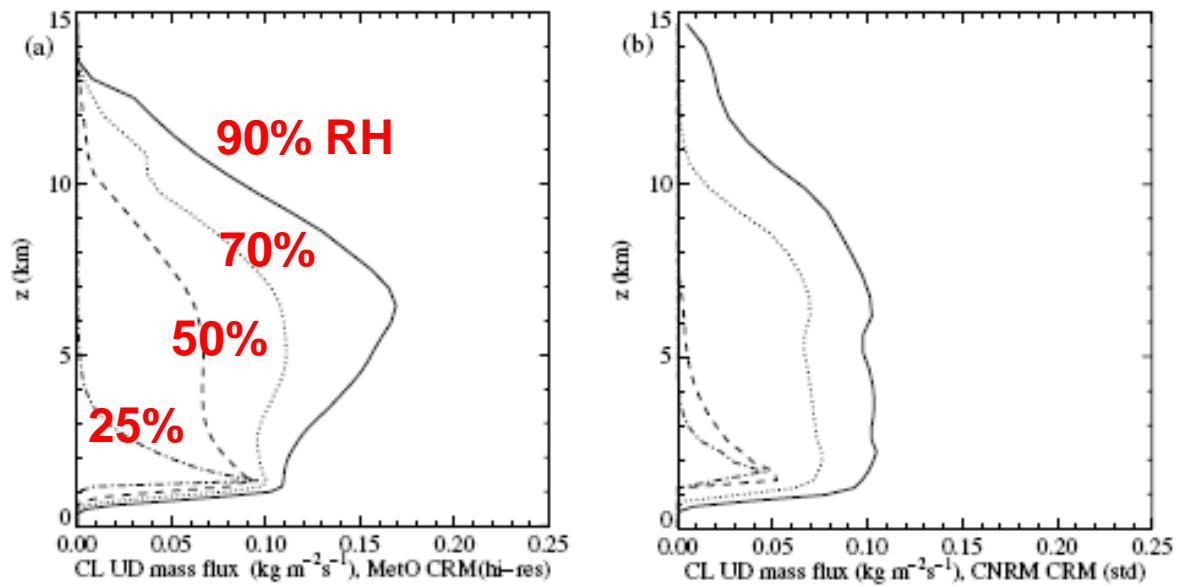
GCM cumulus parameterizations are not sensitive enough to free troposphere humidity to capture the transition from shallow to midlevel to deep convection

(Derbyshire et al., 2004)

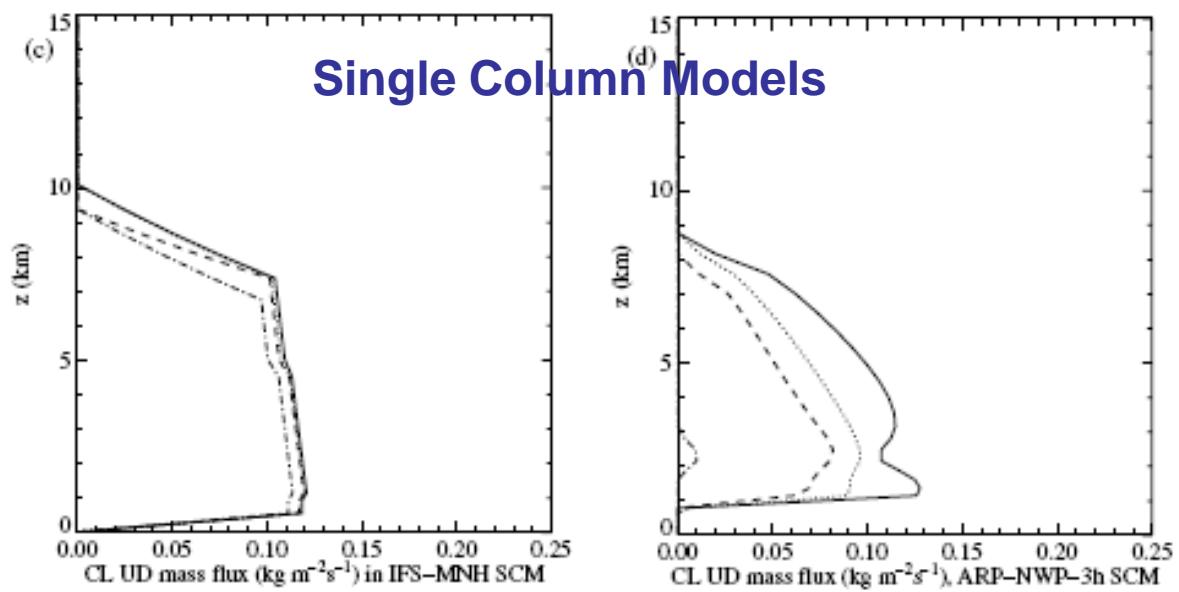
Need stronger entrainment, decreasing as convection deepens

(Grabowski et al., 2006;
Kuang and Bretherton, 2006;
Khairoutdinov and Randall, 2006)

Cloud-Resolving Models



Single Column Models



MJO shallow-deep transition controlled by entrainment of dry vs. humid air into rising cumulus clouds?

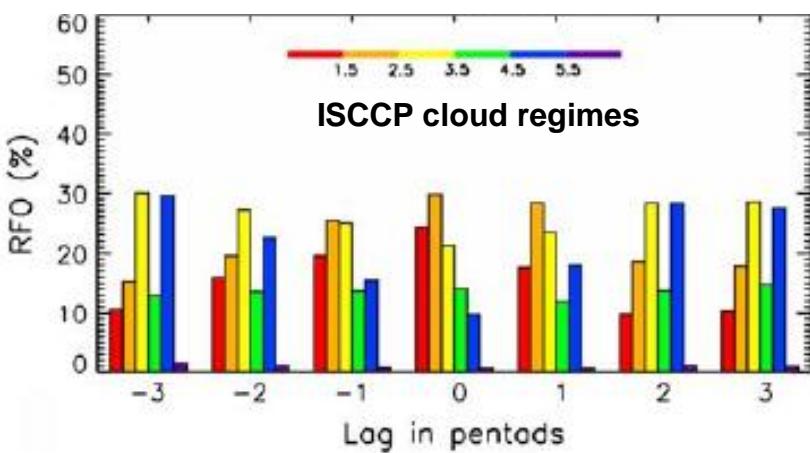
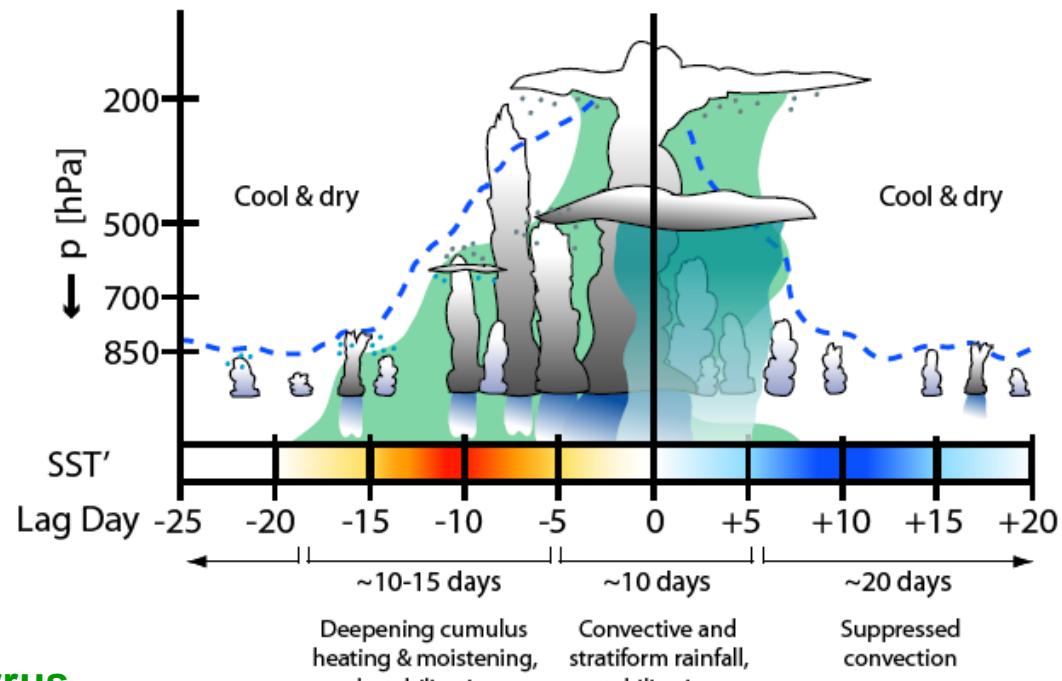


Fig. 10 Relative frequency of occurrence (RFO) of each cloud regime at seven lag periods in pentads of eight MJO events in 4 November–April periods from 1999 to 2003. The color scheme for the cloud regimes is the same as in Fig. 9

red = deep convective
orange = anvil
yellow = congestus

green = thin cirrus
blue = shallow Cu
violet = marine Sc

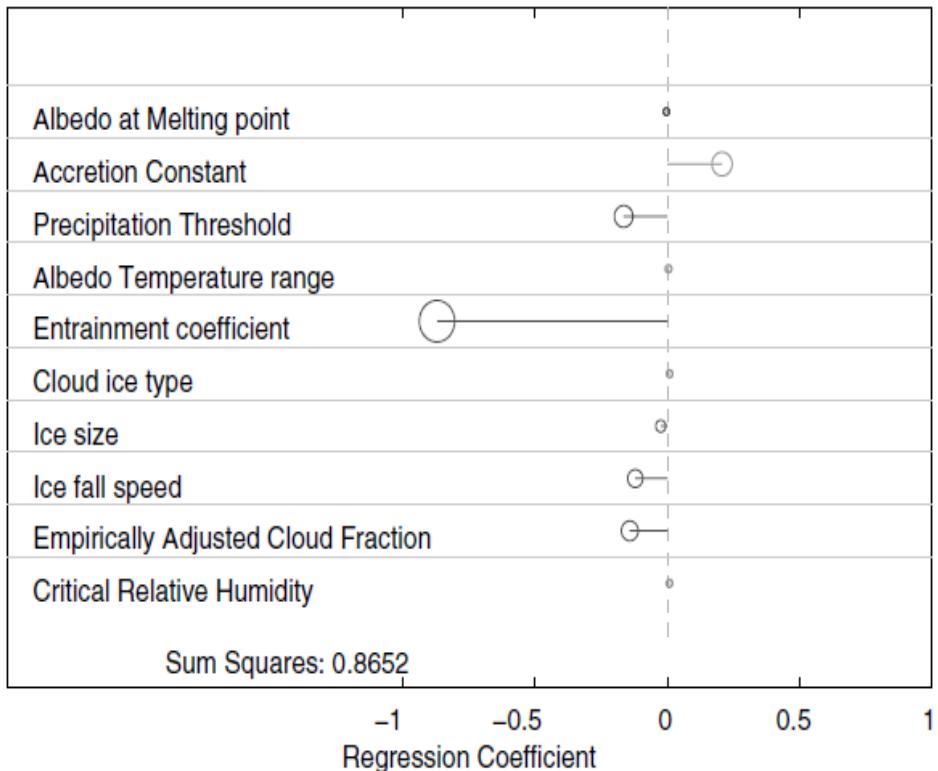
(Chen and Del Genio, 2009)



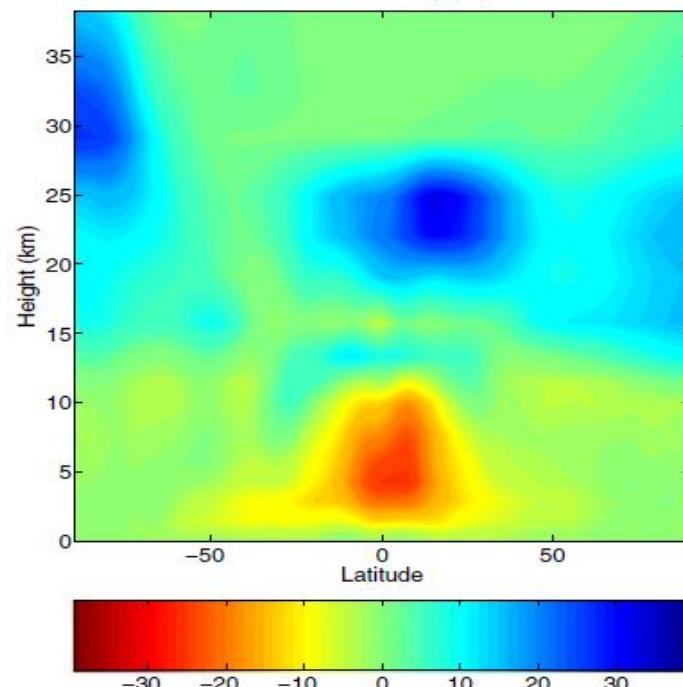
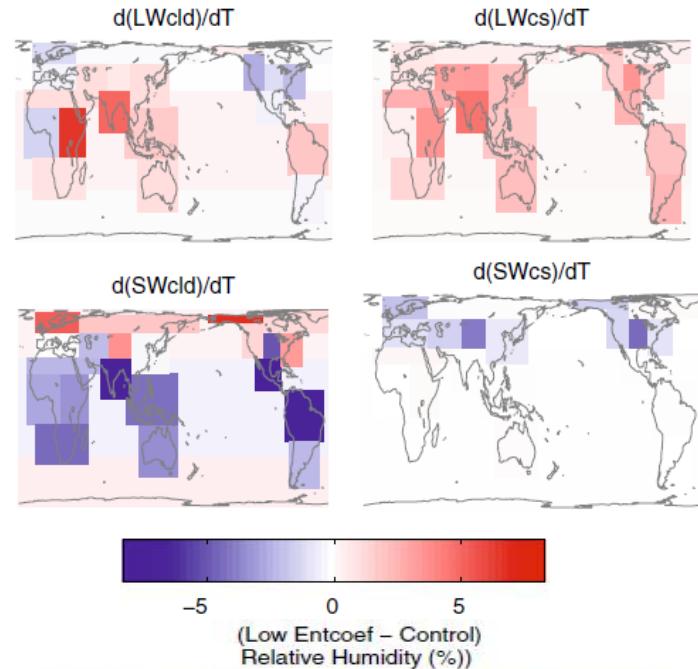
(Benedict and Randall, 2007)

(b)

Feedback Pattern 1



(a)



GCM climate sensitivity is sensitive to entrainment due to shift in convection depth and detrainment of water vapor and condensate

(Sanderson et al., 2008)

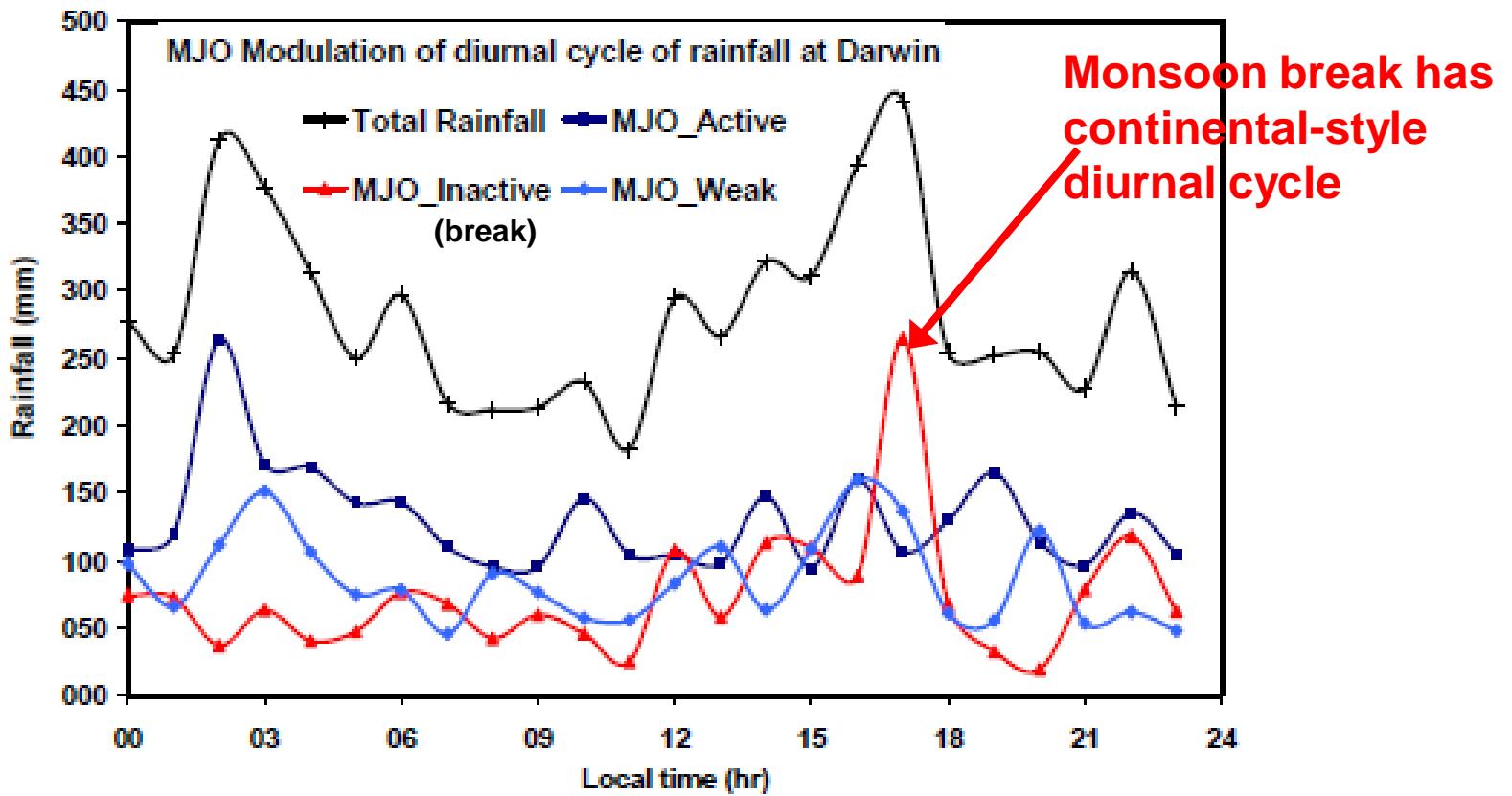
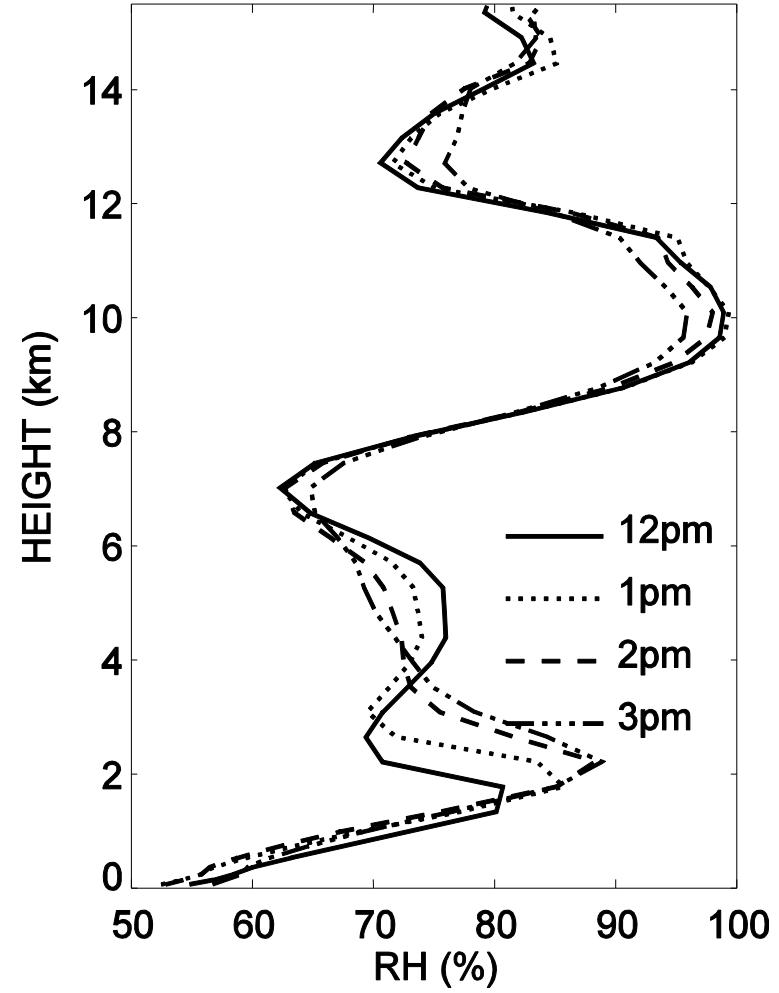
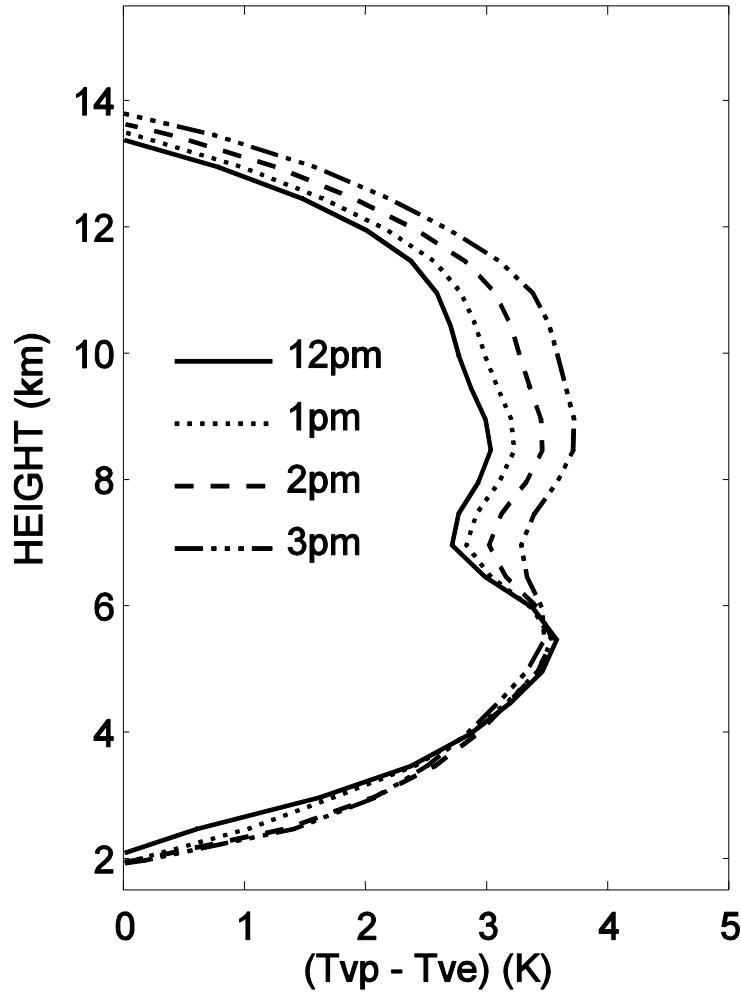


Figure 2. Diurnal cycle of total rainfall of in situ observation from 7 full wet seasons (DJF, 2001-2008) at Darwin Australia and its categorization according to three phases of the MJO.

Rauniyar and Walsh (2009)

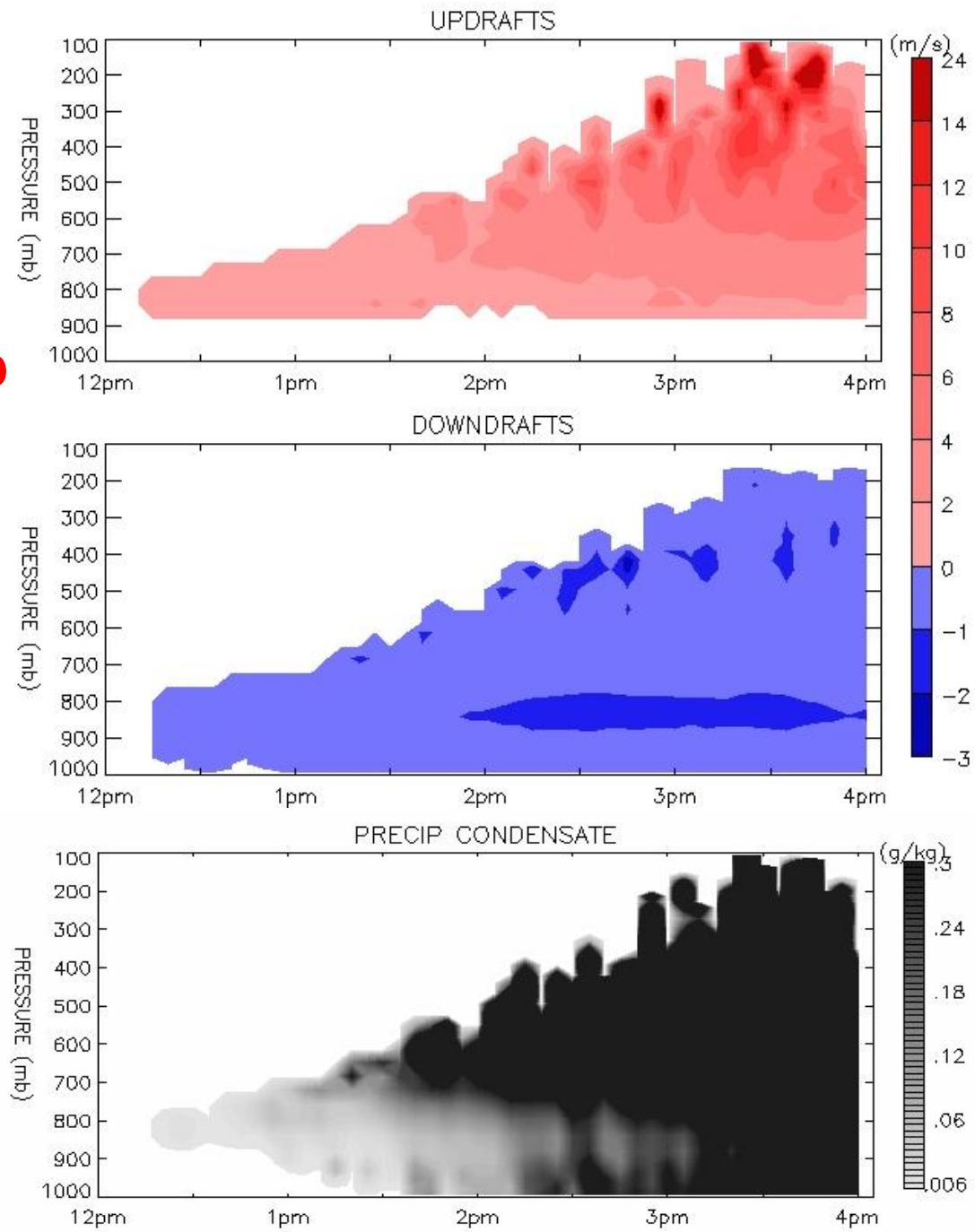


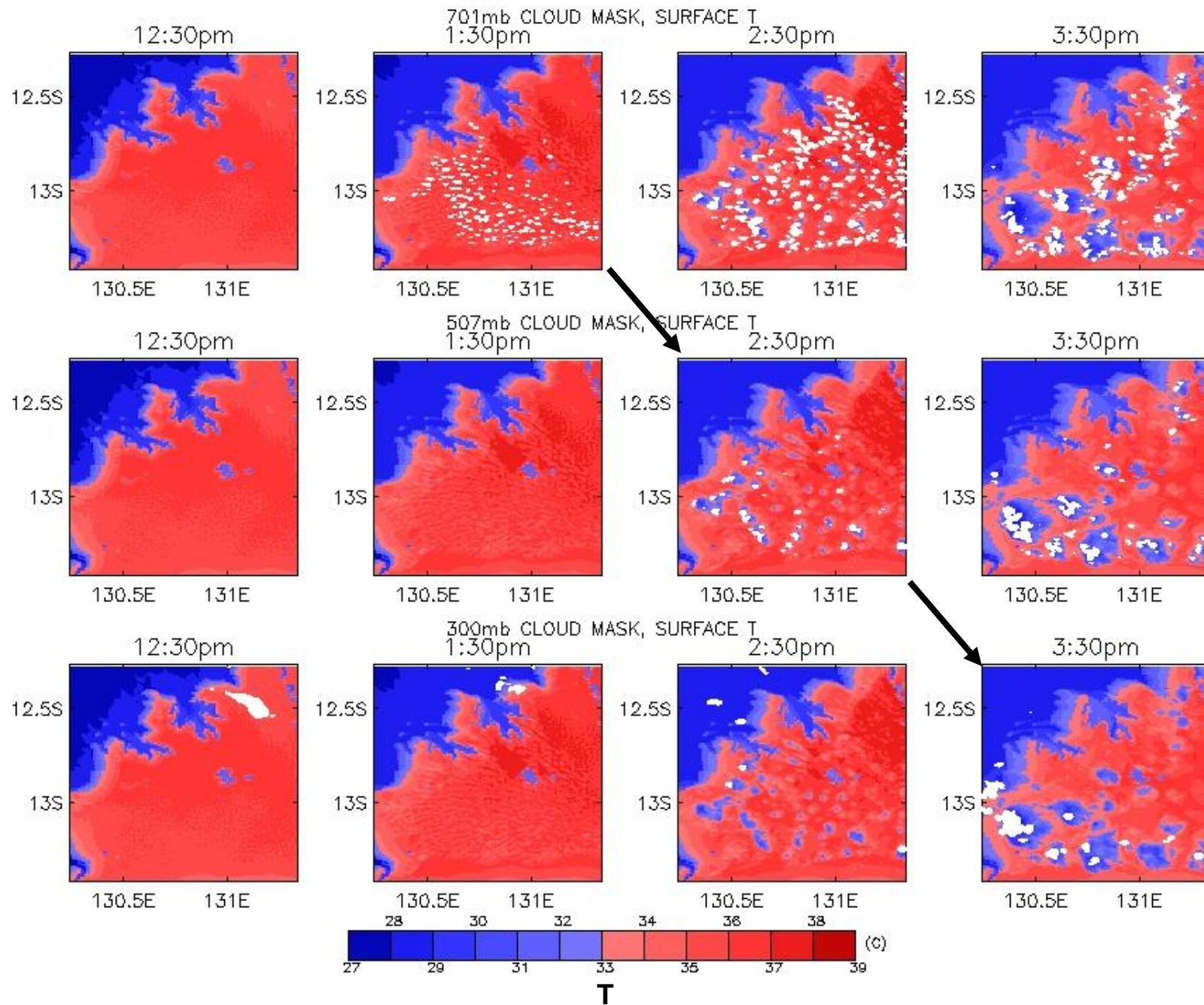
Once parcels penetrate CIN layer, undilute ascent would produce deep convection by noon; RH dry enough for entrainment to be a factor

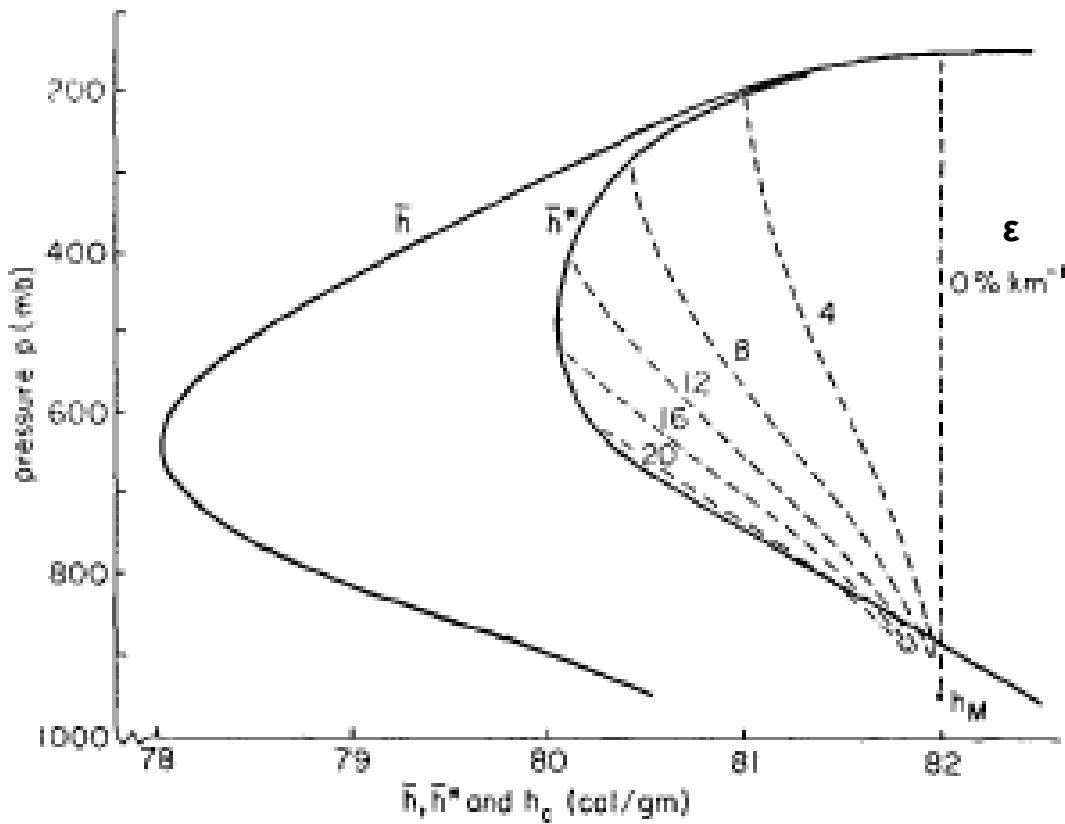
WRF simulation:

- Gradual transition from shallow to deep convection
- Precipitation and downdrafts intensify at ~ 2 PM
- Peak precipitation several hours later

(Del Genio and Wu, 2009)







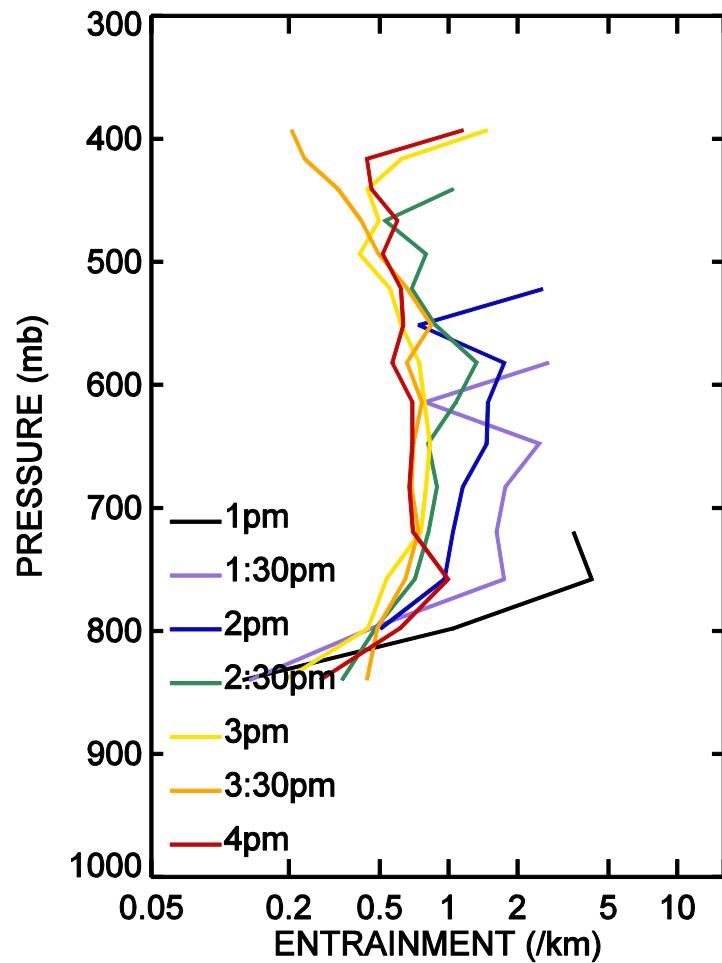
Frozen moist static energy (Kuang and Bretherton, 2006):

$$h = c_p T + gz + L_e q_v - L_s q_i$$

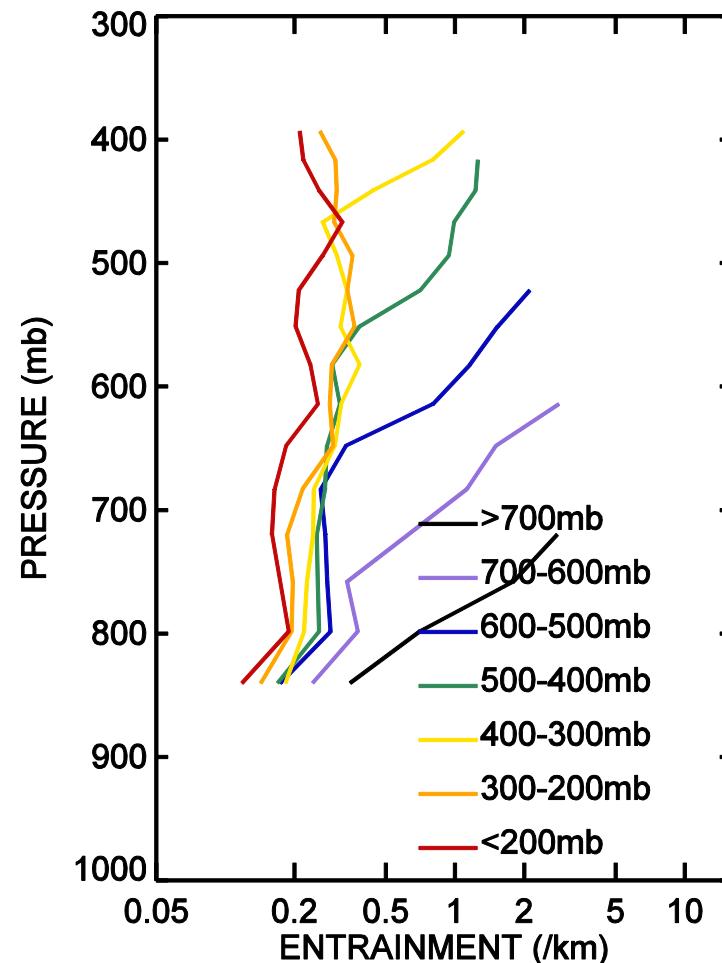
Conserved for undilute ascent

$dh_u/dz = -\varepsilon(h_u - h_e)$ indicates effect of entrainment

By local time



By convection top

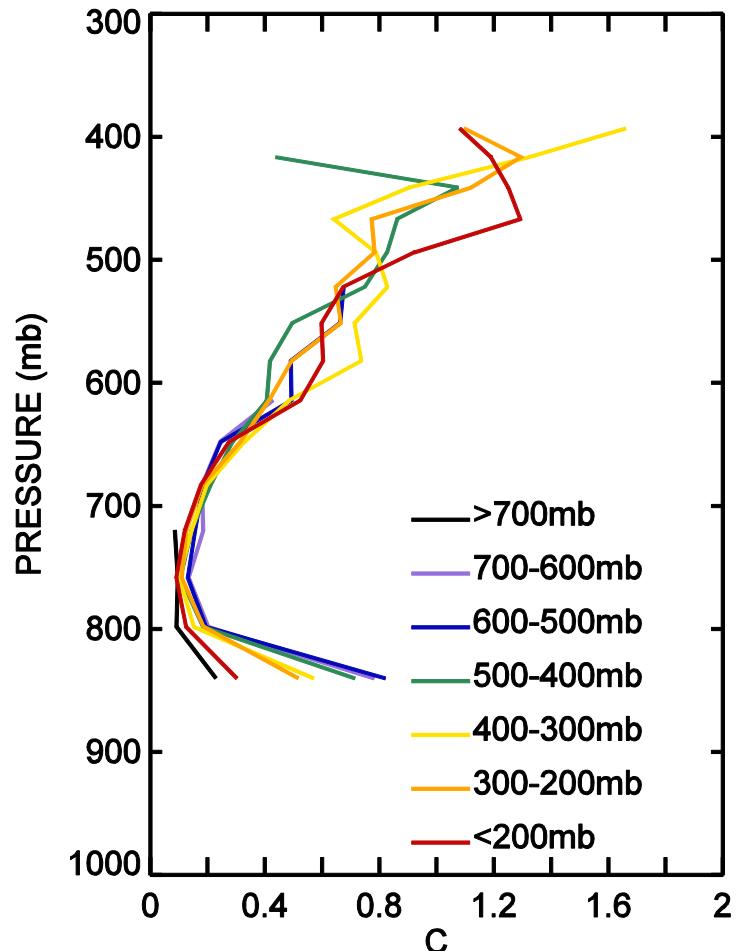


Entrainment weakens as convection deepens...but how to predict that as parcel rises from cloud base?

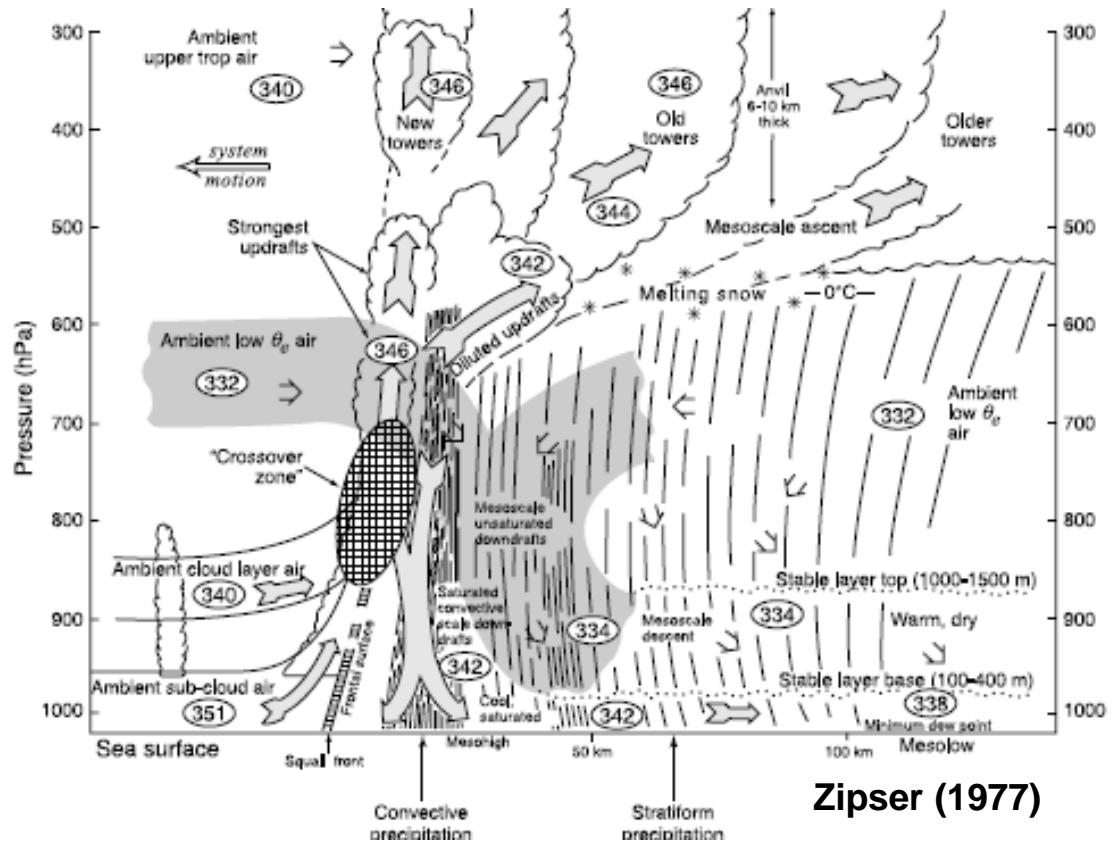
Gregory (2001) entrainment rate parameterization:

$$\varepsilon(z) = CB \Big/ w^2 = Cg \left(\frac{T_v'}{\overline{T}_v} - q_h \right)$$

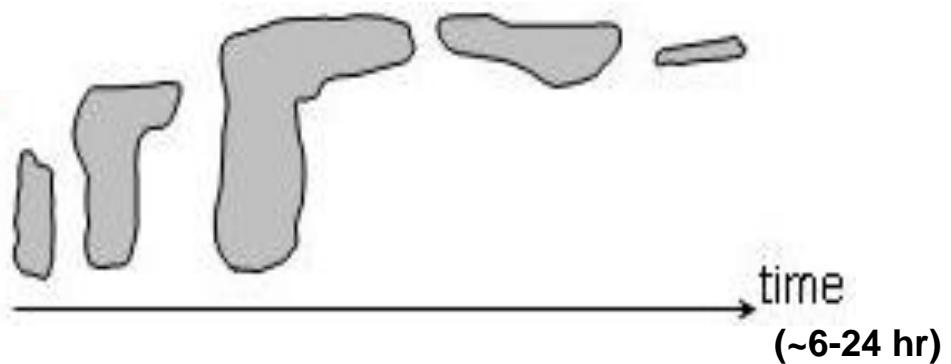
Evaluation using WRF B, w,
and inferred ε in convective
cells: Gregory scheme works
if C (fraction of buoyant TKE
generation used for
entrainment) increases with z

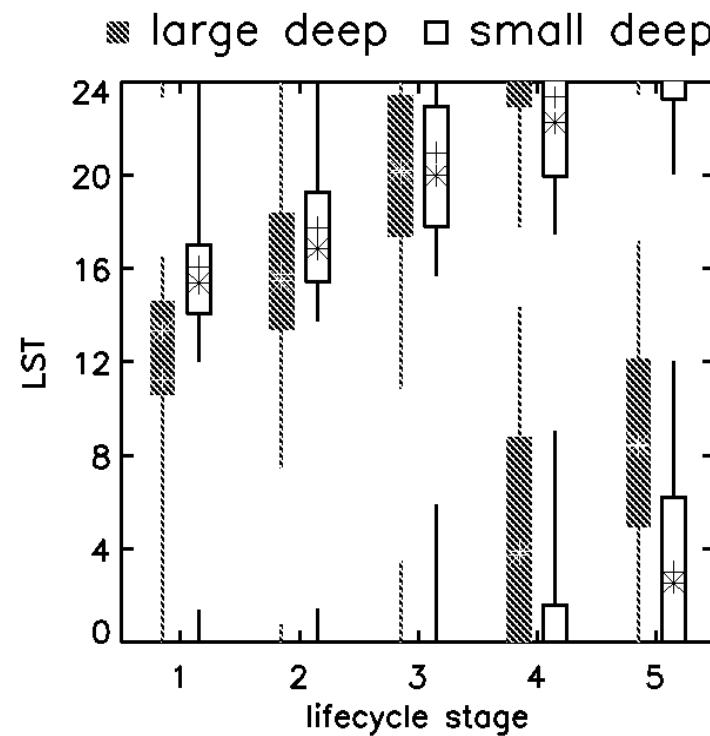
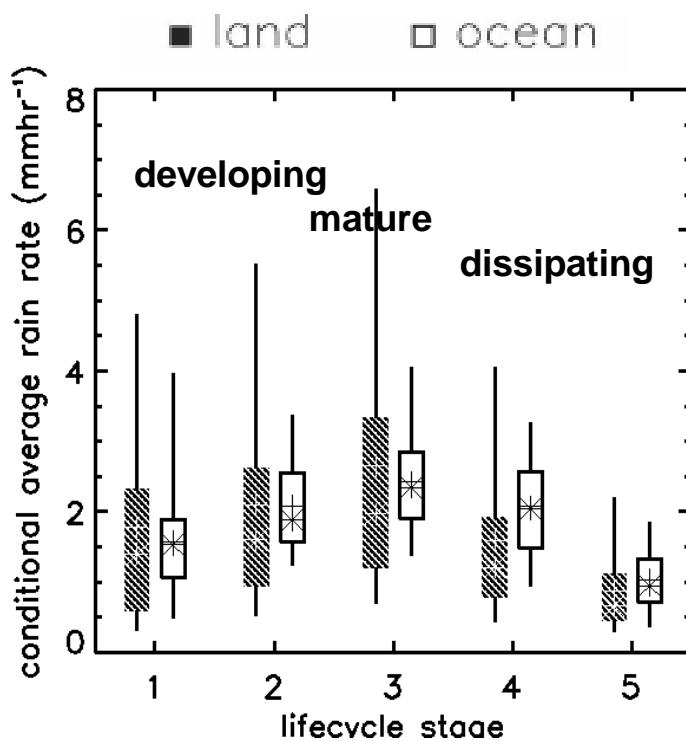


Note: Bechtold et al. (2008) ($\varepsilon = f(RH)$) – currently used in
ECMWF IFS – does not reproduce the WRF behavior



Convective cluster structure and lifecycle

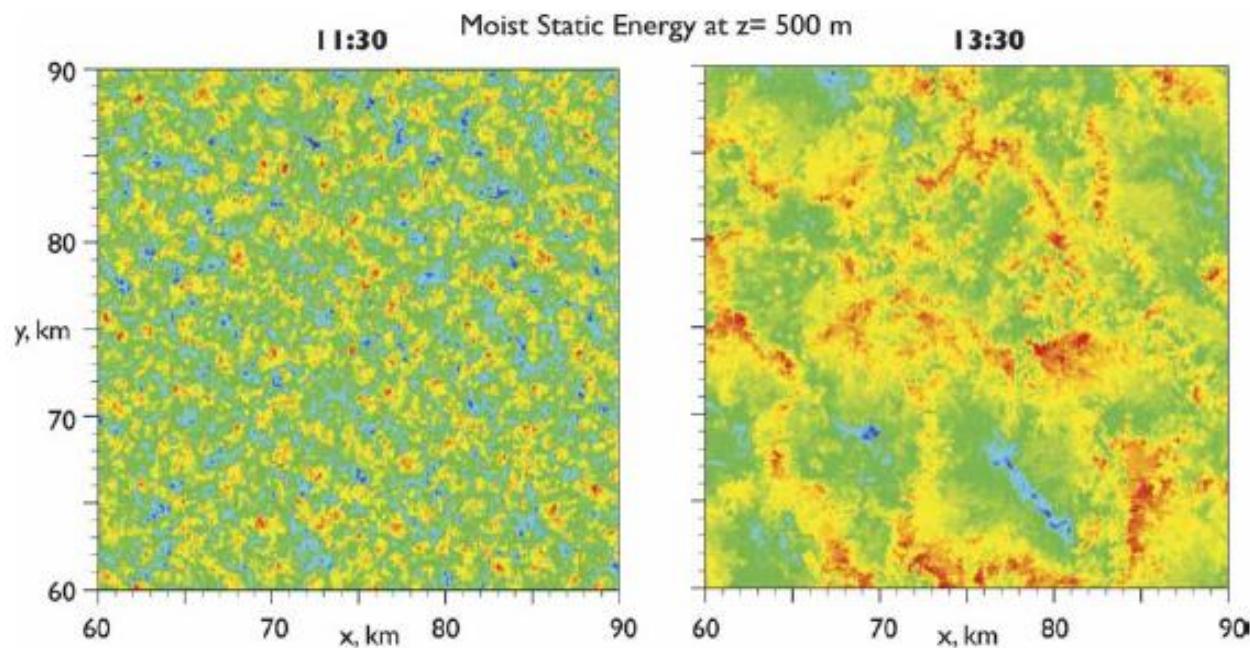
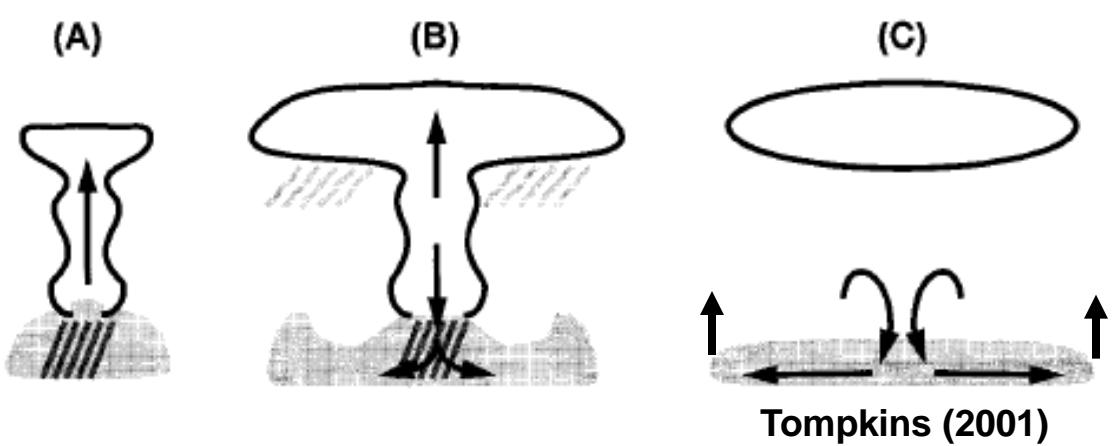




TRMM lifecycle composites: Rain peaks in mature stage; mature stage in late afternoon-early evening, ~6-8 hr after onset

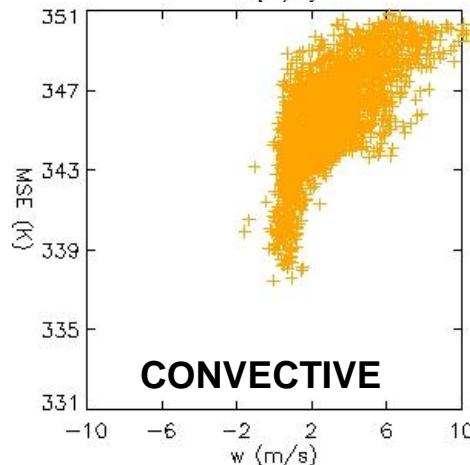
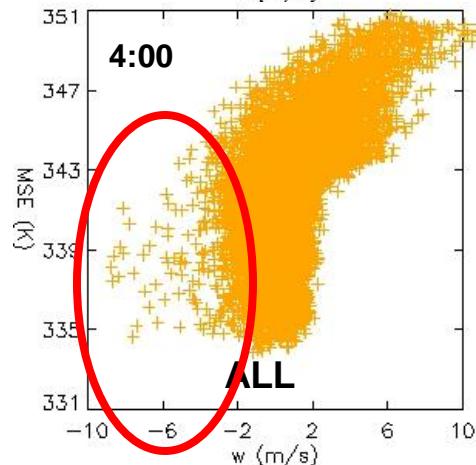
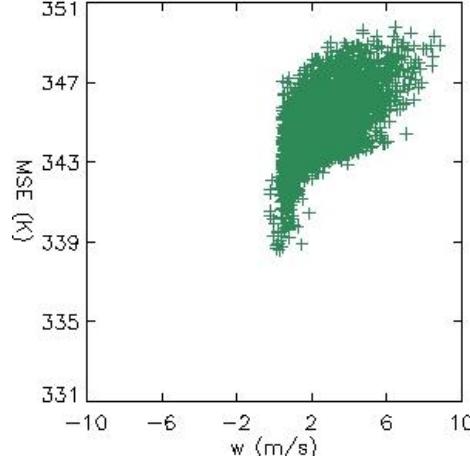
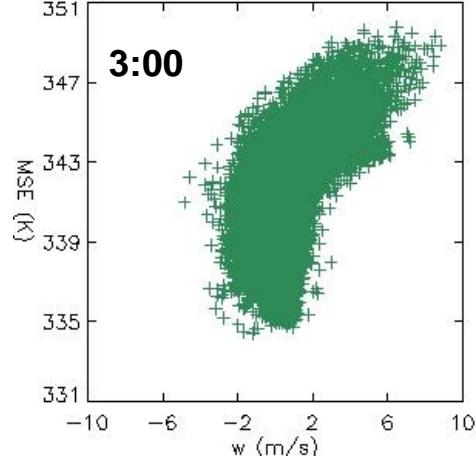
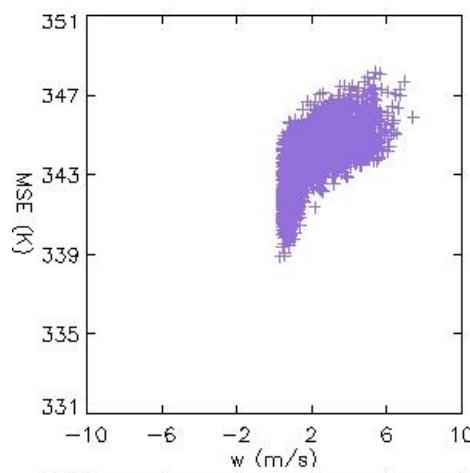
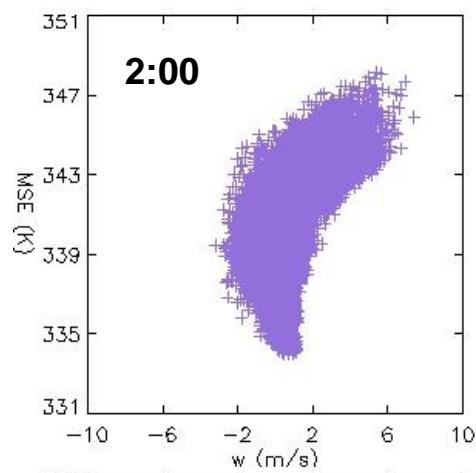
(Futyan and Del Genio, 2007)

How can we sustain convection in GCMs?

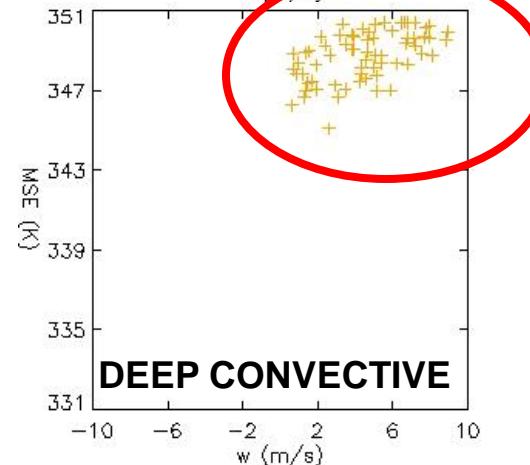
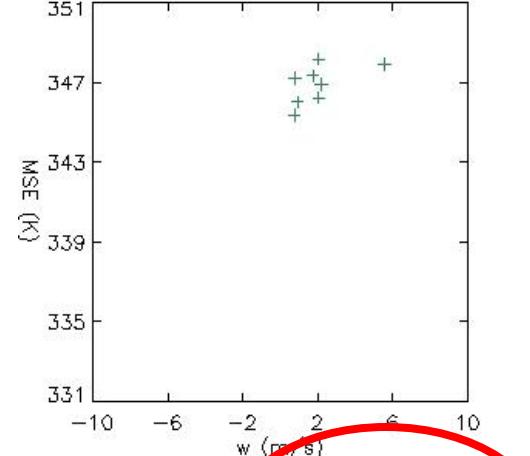


Khairoutdinov and Randall (2006)

Downdraft cold pools converge high-MSE air at gust front



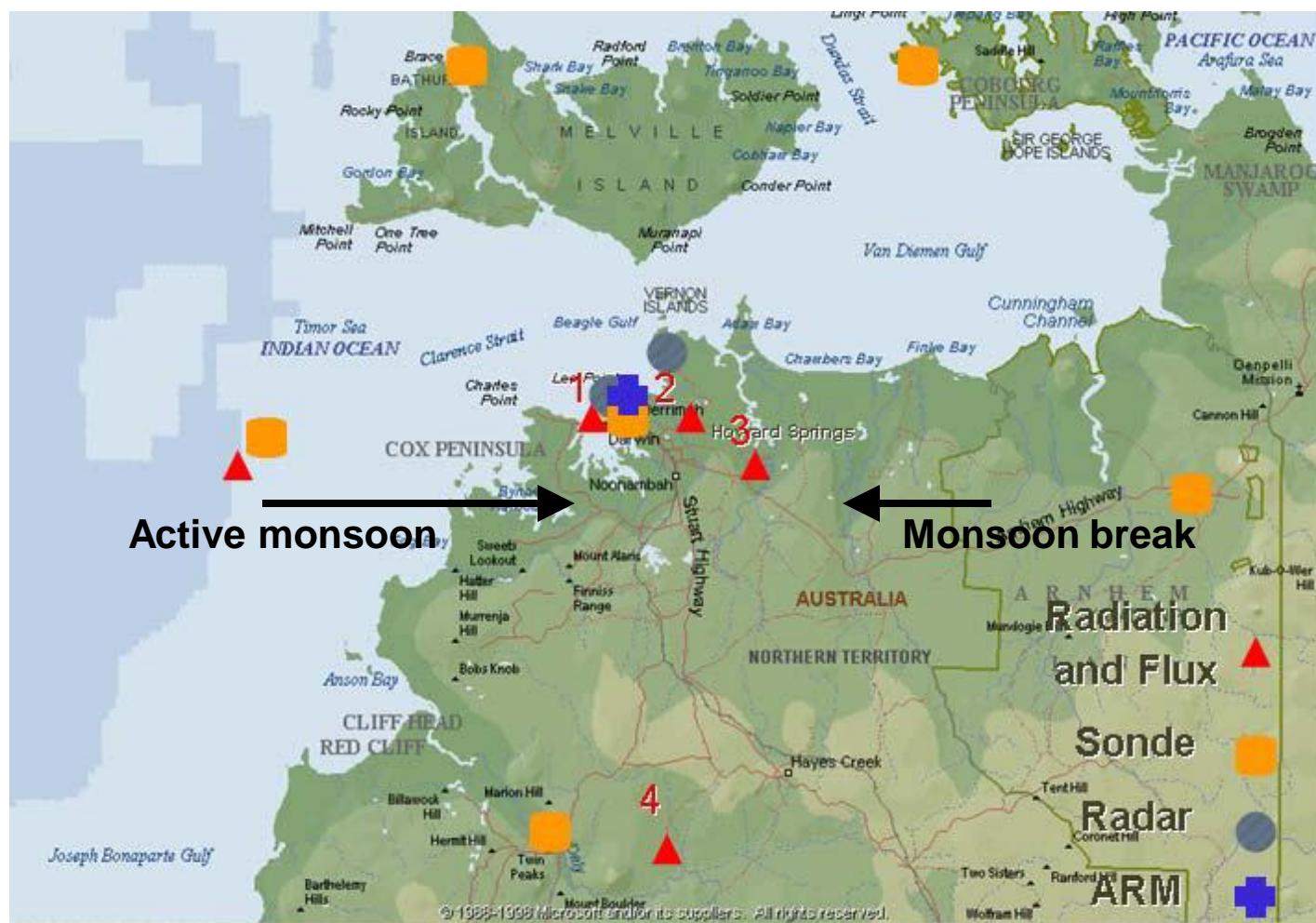
Largest cloud base w in deep convective cells, coincident with downdrafts and cold pools – $\varepsilon \sim 1/w^2$ in Gregory scheme



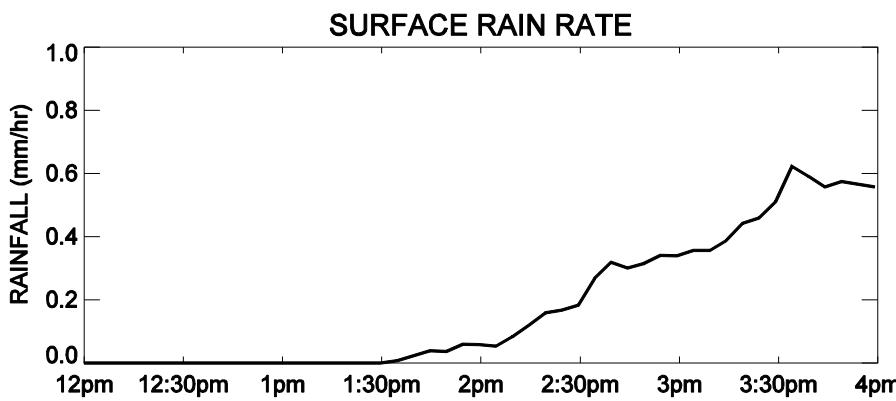
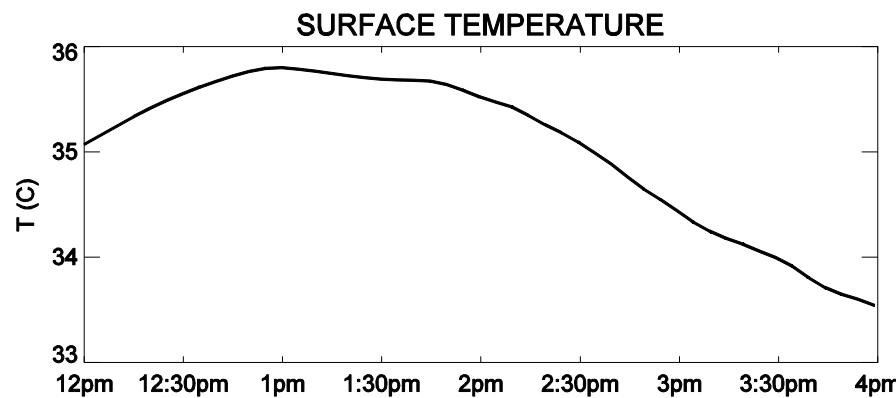
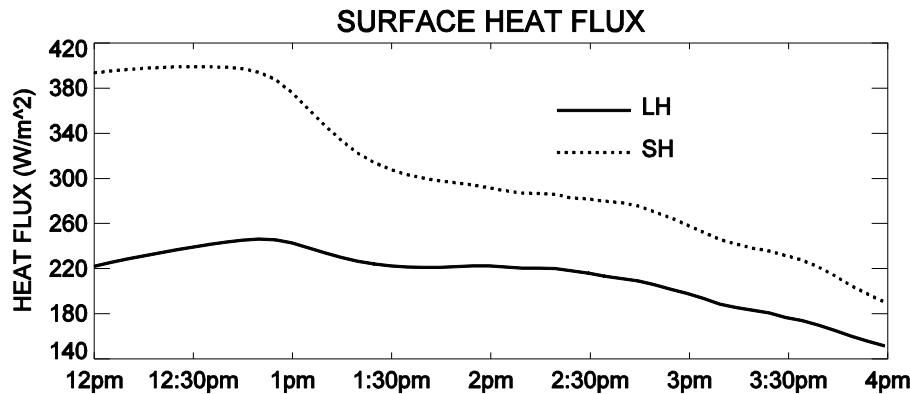
Conclusions

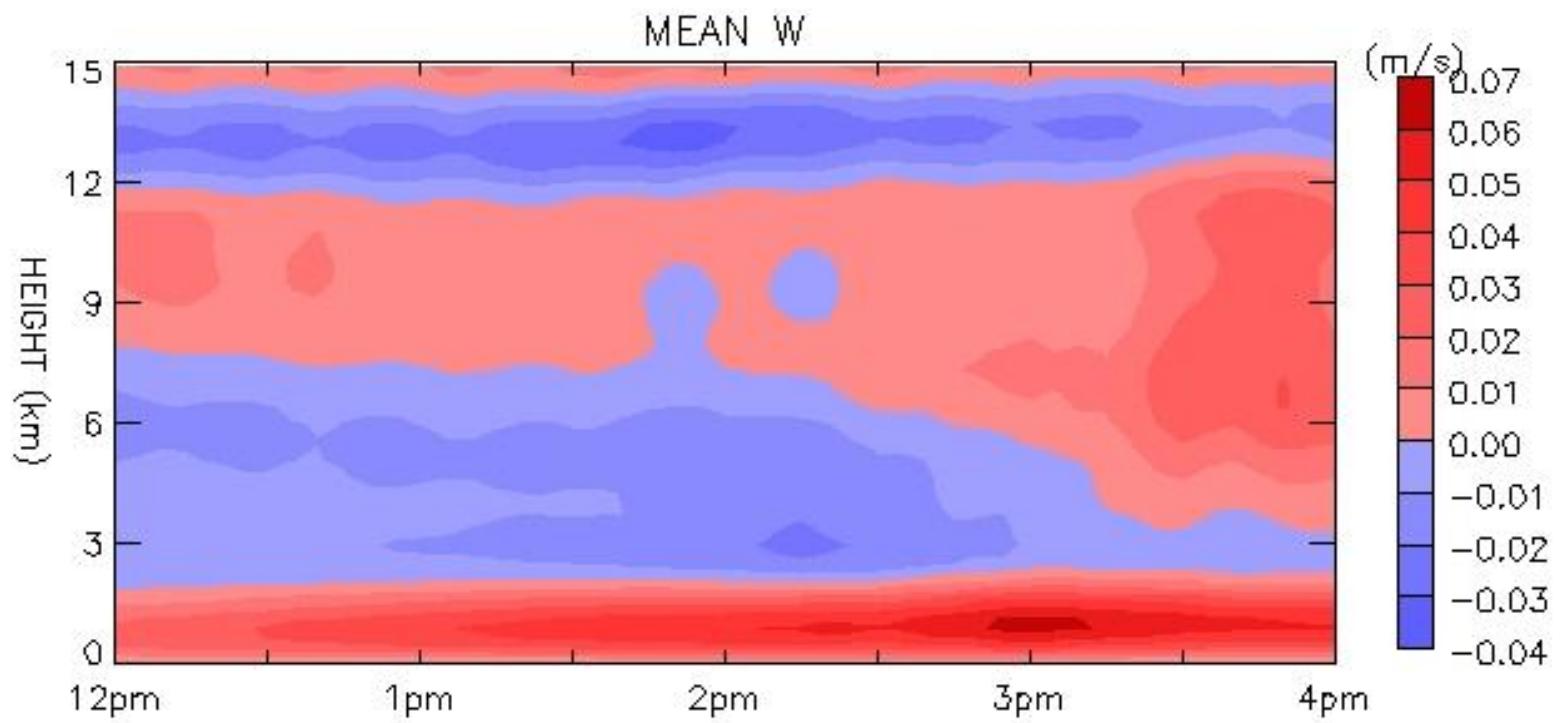
- GCMs rain too early in the day over land
- Entrainment too weak for proper sensitivity to environmental humidity
- Gregory (2001) entrainment parameterization simulates shallow-deep transition timing well
- Need to sustain deep convection for ~6-8 hr after onset to get right timing of rainfall peak
- Downdraft cold pool effect on cloud base w important for smaller entrainment rate of deep convection?

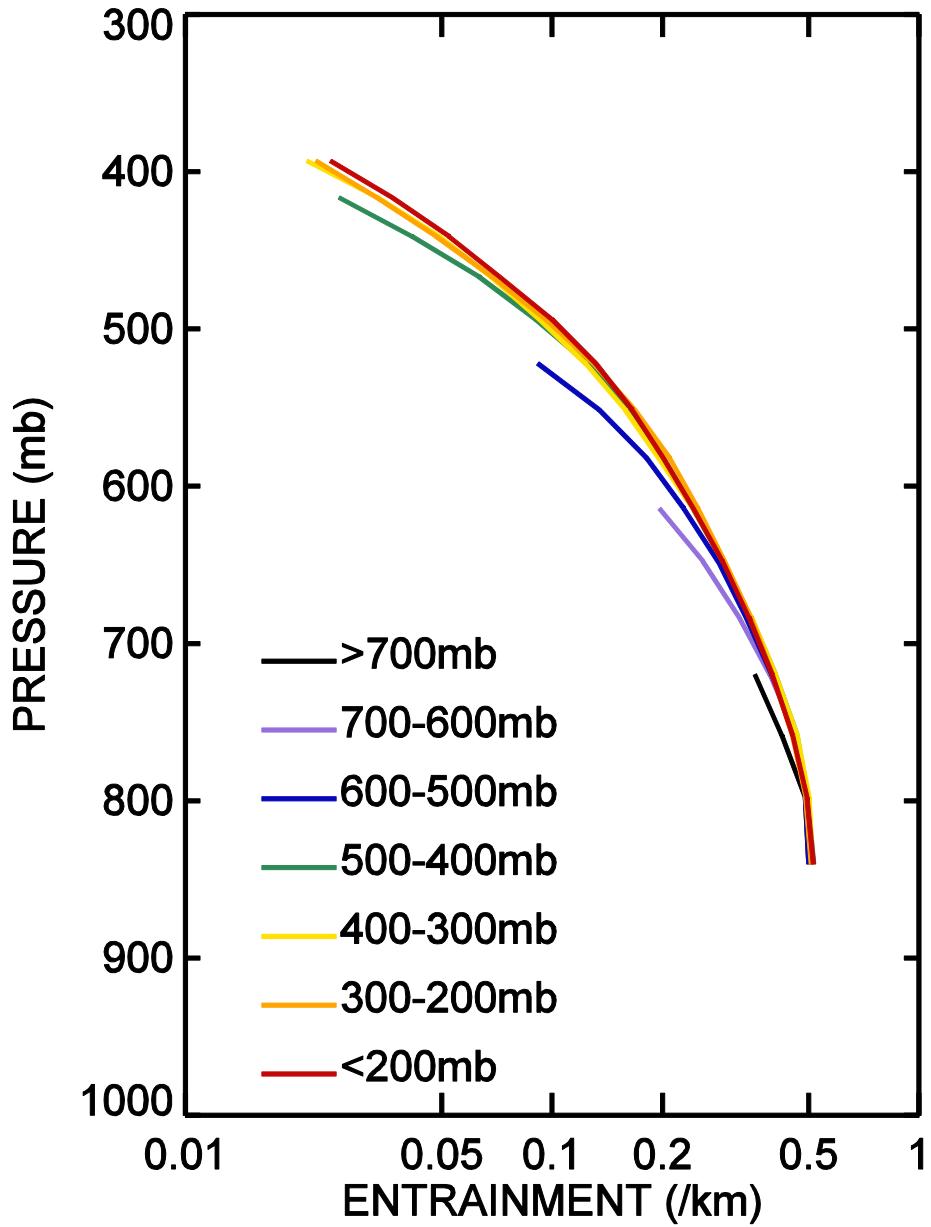
TWP-ICE Experiment



WRF 600 m/50 L resolution simulations of monsoon break

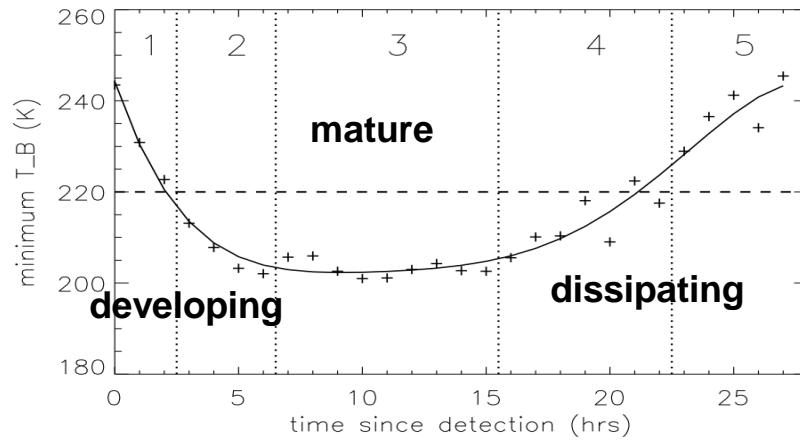
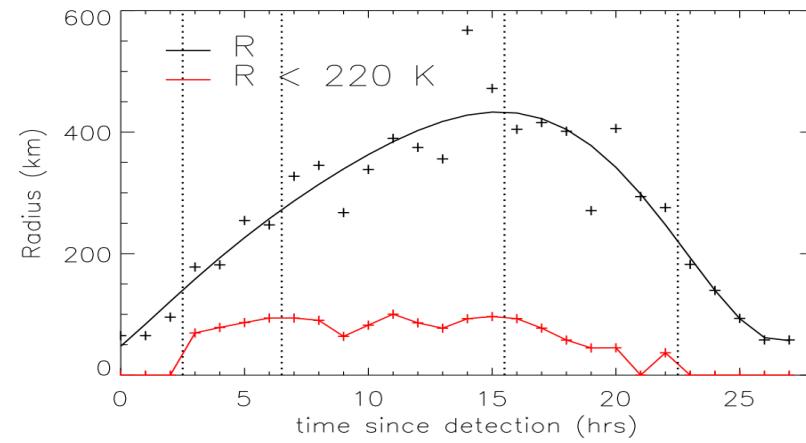
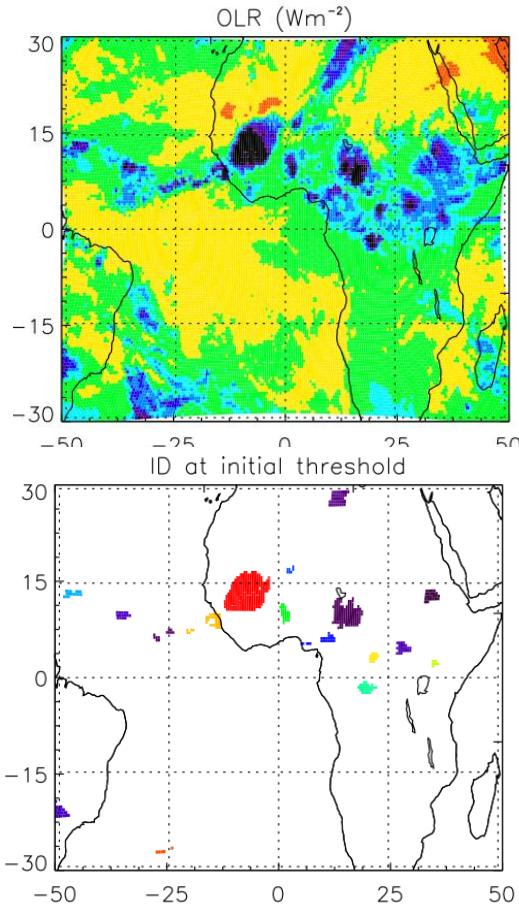






Bechtold et al. (2008)

Detection and tracking of tropical convective clusters



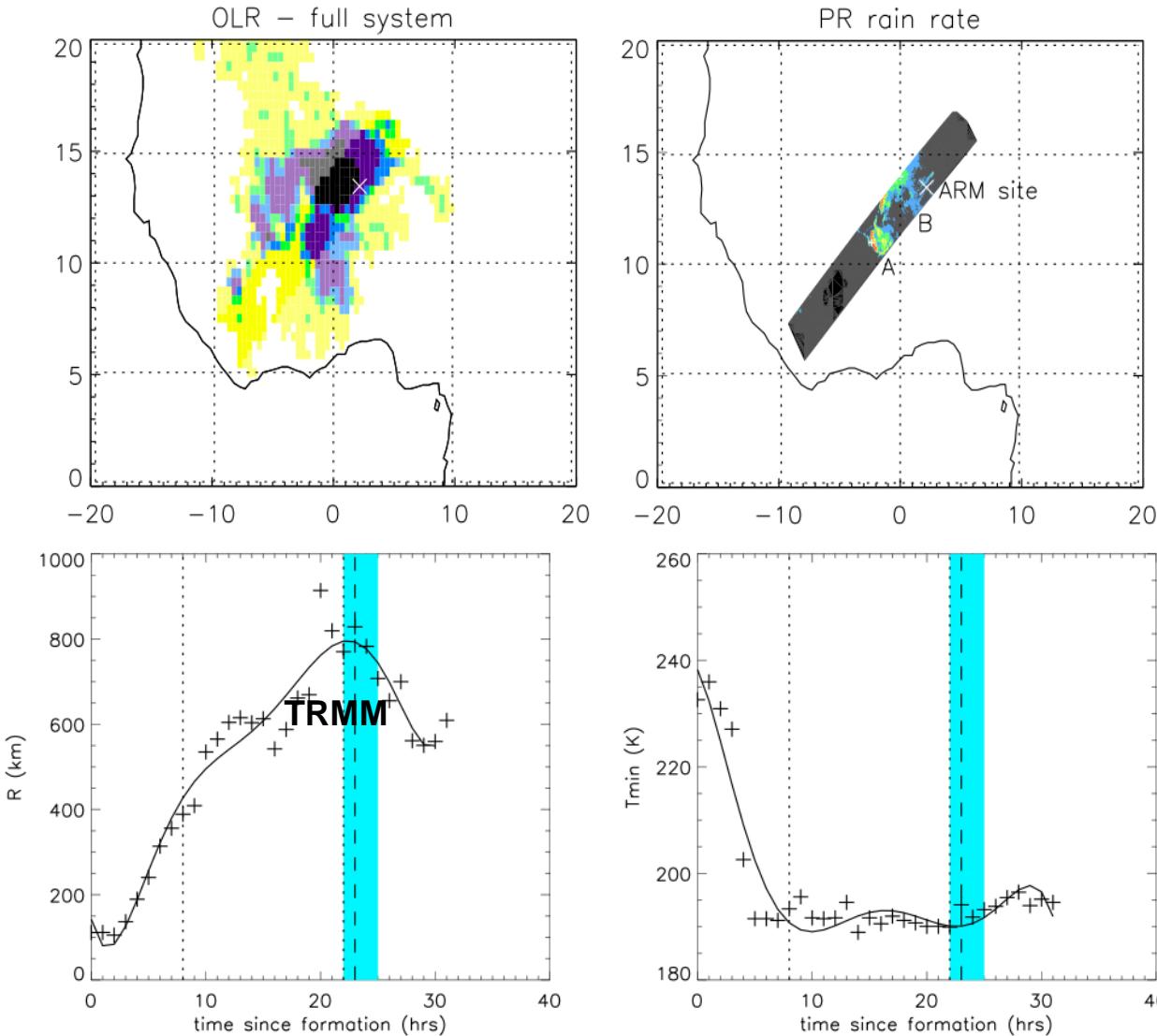
GERB OLR thresholds define cluster; track via maximum overlap

Evolution of cluster radius and height defines lifecycle phases

Futyan and Del Genio (2007)

*** Possible only with geostationary data ***

Mapping of non-geostationary low earth orbit data (TRMM) onto geostationary lifecycle phase allows composite lifecycle to be constructed



**Example:
Cluster in
mature phase
passing over
AMMA site**